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(54) **SPARK PLUG**

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(58) **Field of Classification Search**
CPC H01T 13/41; H01T 13/05; H01T 13/20
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,304,894 A * 4/1994 Stimson C03C 8/14
252/507
2011/0133626 A1 6/2011 Shibata et al. 313/141
2013/0264939 A1 10/2013 Fukushima et al. 315/58

FOREIGN PATENT DOCUMENTS

CN 103262369 A 9/1990 .... H01C 7/00
CN 103262369 A 8/2013 .... H01T 13/20
(Continued)

OTHER PUBLICATIONS

International Search Report issued in corresponding International Patent Application No. PCT/JP2014/002900, dated Jul. 1, 2014.
(Continued)

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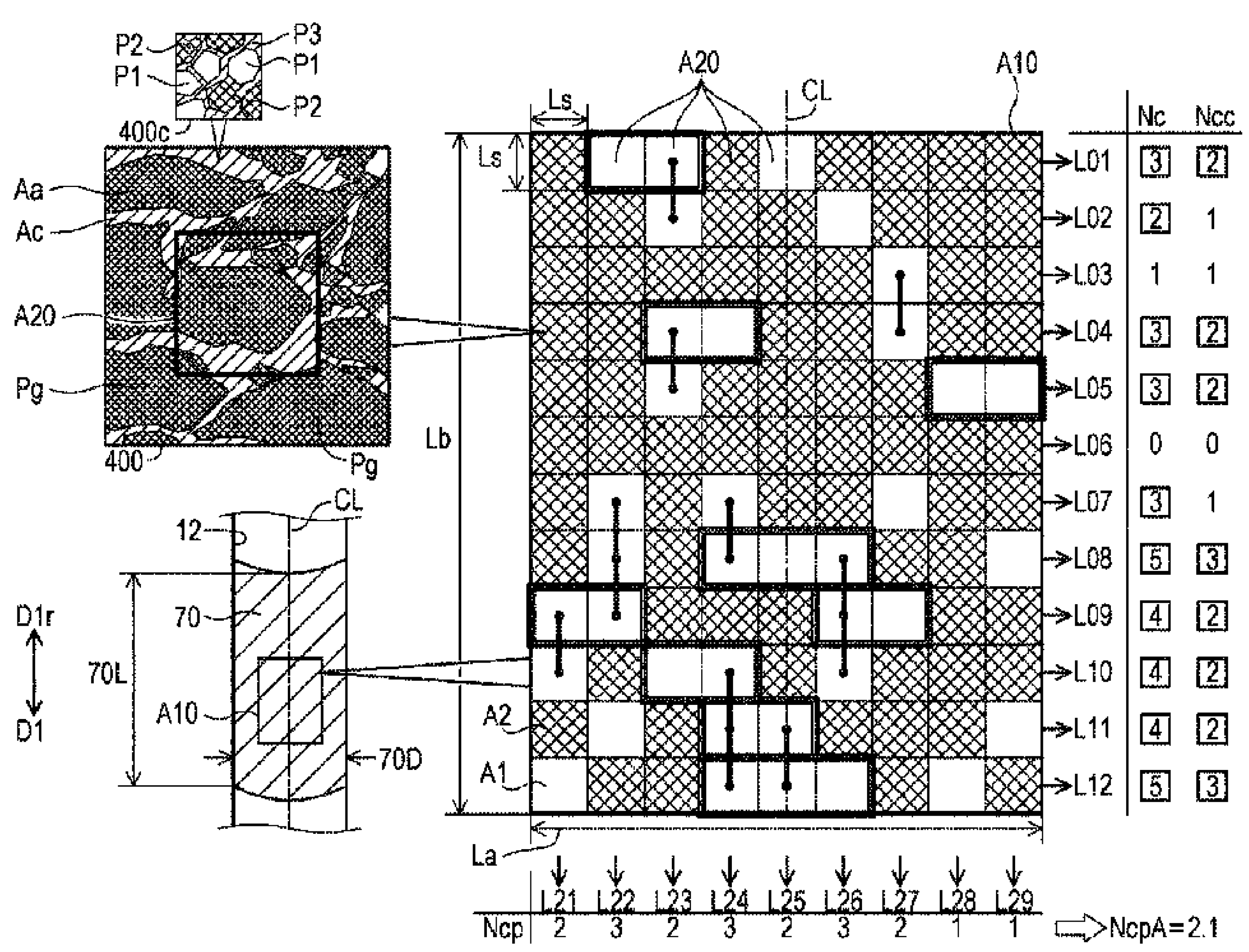
(57) **ABSTRACT**

A resistor element of a spark plug containing ZrO_2, wherein a target region is defined by a rectangular region where the size in the direction perpendicular to an axial line is 1800 μm and the size in the direction of the axial line is 2400 μm. In the case where the target region is divided into a plurality of square regions having lengths of 200 μm on a side, a transverse line-shaped region is defined by a region in a line shape that is constituted of nine square regions arranged in the direction perpendicular to the axial line. A first type region is defined by the square region where a proportion of an area of ZrO_2 is 25% or more, and a second type region is defined by the square region where a proportion of an area of ZrO_2 is less than 25%.

9 Claims, 2 Drawing Sheets



(51) **Int. Cl.**

H01T 13/41	(2006.01)
H01T 13/05	(2006.01)

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

EP	0170975	A1	2/1986	.... H01T 13/41
JP	61/39386	A	2/1986	.... H01T 13/20
JP	2005/327743	A	11/2005	.... H01C 7/00
WO	WO 2009/154070	A1	12/2009	.... H01C 13/003

OTHER PUBLICATIONS

Office Action received in corresponding Chinese Patent Application No. 201480047808.3, dated Jul. 3, 2016 (English translation provided).

* cited by examiner

FIG. 1

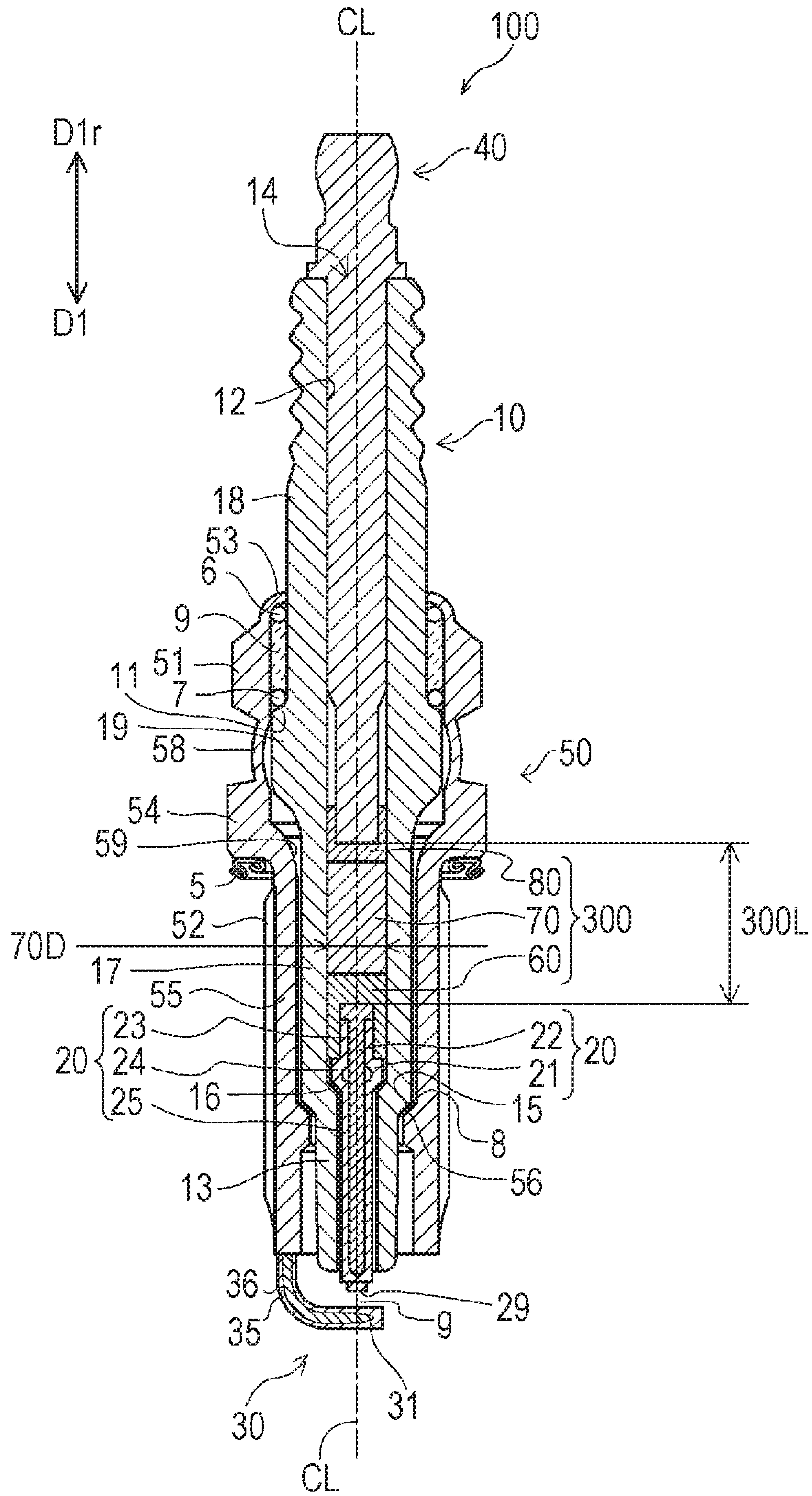

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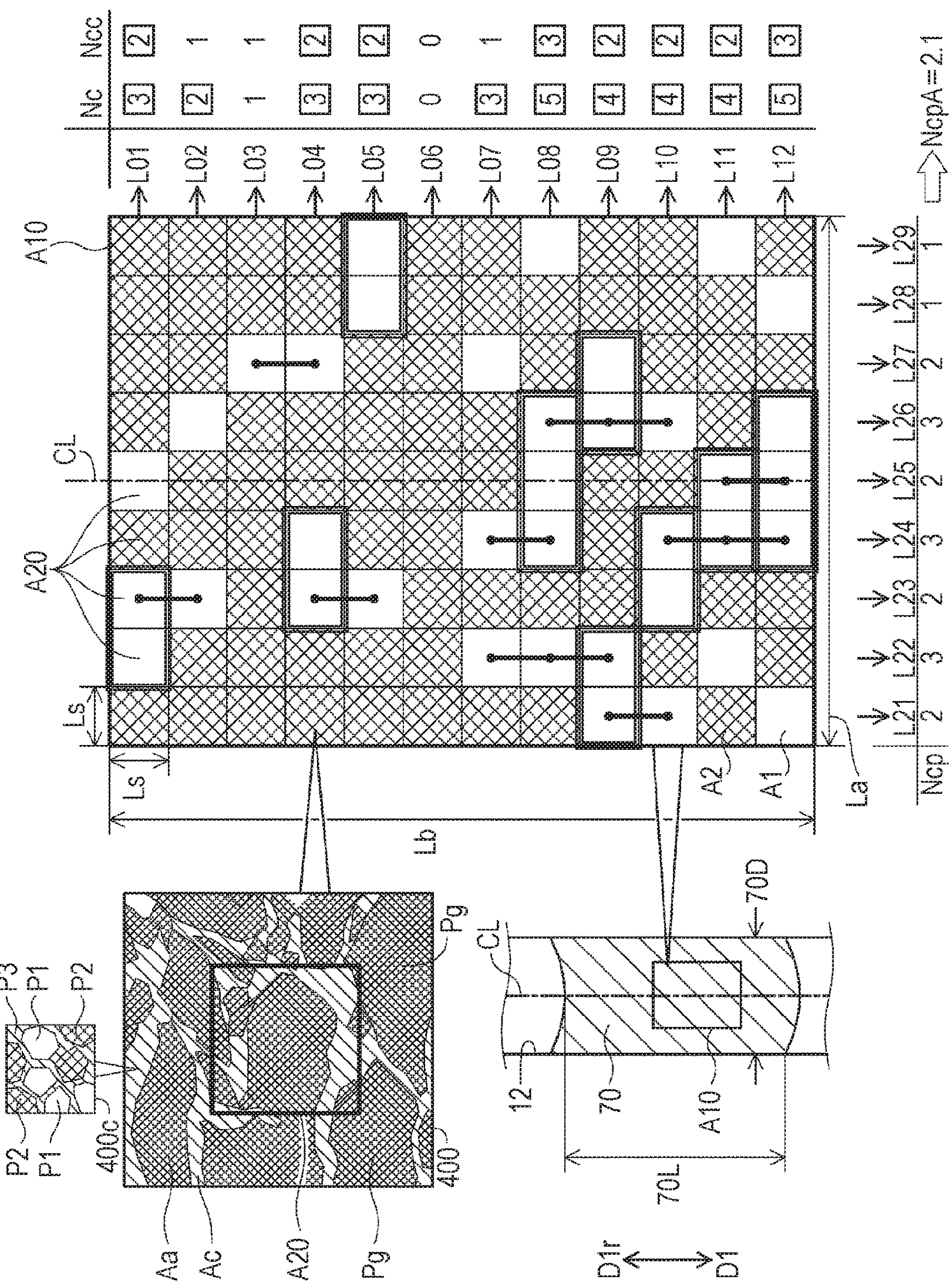
FIG. 2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SPARK PLUG

RELATED APPLICATIONS

This application is a National Stage of International Application No. PCT/JP2014/002900 filed Jun. 2, 2014, which claims the benefit of Japanese Patent Application No. 2014-022891, filed Feb. 7, 2014.

FIELD OF THE INVENTION

The present invention relates to a spark plug.

BACKGROUND OF THE INVENTION

Conventionally, a spark plug is used in an internal combustion engine. To reduce the radio wave noise generated by ignition, there is proposed a technique that arranges a resistor element between a center electrode and a terminal metal fitting.

Nowadays, further improvements in electrical noise performance and in durability are required due to a high-power engine or similar reason.

The main advantage of the present invention is to improve the suppression performance of the radio wave noise and the service life of the resistor element.

SUMMARY OF THE INVENTION

The present invention has been conceived to solve at least a part of the above-mentioned problems, and can be realized as the following application examples.

Application Example 1

In accordance with a first aspect of the present invention, there is provided a spark plug that includes an insulator, a center electrode, a terminal metal fitting, and a connecting portion. The insulator has a through hole extending in a direction of an axial line. The center electrode is at least partially inserted into a front end side of the through hole. The terminal metal fitting is at least partially inserted into a rear end side of the through hole. The connecting portion electrically connects the center electrode and the terminal metal fitting together within the through hole. The connecting portion includes a resistor element. The resistor element includes an aggregate, a filler containing ZrO_2, and carbons. In a cross section including the axial line of the resistor element, a center line is defined by the axial line. A target region is defined by a rectangular region where a size in a direction perpendicular to the axial line is 1800 μm and a size in a direction of the axial line is 2400 μm. A transverse line-shaped region is defined by a region in a line shape that is constituted of nine square regions arranged in the direction perpendicular to the axial line in the case where the target region is divided into a plurality of square regions having lengths of 200 μm on a side. A first type region is defined by the square region where a proportion of an area of ZrO_2 is 25% or more. A second type region is defined by the square region where a proportion of an area of ZrO_2 is less than 25%. In this case, a total number of the transverse line-shaped regions including two or more of the first type regions is equal to or more than 5.

With this configuration, ensuring a proper state within the resistor element allows improving both the suppression performance of radio wave noise and the service life of the resistor element.

Application Example 2

In accordance with a second aspect of the present invention, there is provided a spark plug according to the application example 1, wherein a total number of the transverse line-shaped regions including two or more of the consecutive first type regions is equal to or more than 5.

With this configuration, ensuring a proper state within the resistor element allows improving both the suppression performance of radio wave noise and the service life of the resistor element.

Application Example 3

In accordance with a third aspect of the present invention, there is provided a the spark plug according to the application example 1 or 2, wherein the filler contains TiO_2, and a weight proportion of Ti to Zr in the resistor element is equal to or more than 0.05 and equal to or less than 6.

With this configuration, ensuring a proper weight proportion of Ti to Zr in the filler allows improving both the suppression performance of radio wave noise and the service life of the resistor element.

Application Example 4

In accordance with a fourth aspect of the present invention, there is provided a spark plug according to any one of the application examples 1 to 3, wherein, in a cross section perpendicular to the axial line in the resistor element, a minimum value of an outer diameter of a portion in contact with an inner peripheral surface of the insulator over a whole circumference is equal to or less than 3.5 mm.

This configuration allows improving both the suppression performance of radio wave noise and the service life of the resistor element in the case where the resistor element with the outer diameter of 3.5 mm or less is used.

Application Example 5

In accordance with a fifth aspect of the present invention, there is provided a spark plug according to the application example 4, wherein the minimum value of the outer diameter is equal to or less than 2.9 mm.

This configuration allows improving both the suppression performance of radio wave noise and the service life of the resistor element in the case where the resistor element with the outer diameter of 2.9 mm or less is used.

Application Example 6

In accordance with a sixth aspect of the present invention, there is provided a spark plug according to any one of the application examples 1 to 5, wherein a distance in the axial line between a rear end of the center electrode and a front end of the terminal metal fitting is equal to or more than 15 mm.

This configuration allows improving both the suppression performance of radio wave noise and the service life of the resistor element in the case where the resistor element is arranged between the center electrode and the terminal metal fitting that are arranged at a distance of 15 mm or more from each other.

Application Example 7

In accordance with a seventh aspect of the present invention, there is provided a spark plug according to any one of the application examples 1 to 6, wherein a longitudinal line-shaped region is defined by a line-shaped region that is constituted of 12 of the square regions arranged in a direction parallel to the axial line. A longitudinal maximum consecutive number is defined by a maximum value of a consecutive number of the first type regions in one longitudinal line-shaped region. In this case, an average value of the longitudinal maximum consecutive number in nine longitudinal line-shaped regions included in the target region is equal to or less than 5.0.

This configuration allows further improving the suppression performance of radio wave noise.

Application Example 8

In accordance with an eighth aspect of the present invention, there is provided a spark plug according to any one of the application examples 1 to 7, wherein a total number of the transverse line-shaped regions including two or more of the consecutive first type regions is equal to or more than 7.

This configuration allows further improving the service life of the resistor element.

Application Example 9

In accordance with a ninth aspect of the present invention, there is provided a spark plug according to any one of the application examples 1 to 8, wherein, when a transverse maximum consecutive number is defined by a maximum value of a consecutive number of the first type regions in one transverse line-shaped region, an average value of the transverse maximum consecutive number in 12 transverse line-shaped regions included in the target region is larger than an expected value of the transverse maximum consecutive number calculated from a total number of the first type regions in the target region.

This configuration allows further improving the service life of the resistor element.

Here, the present invention can be realized by various forms, for example, can be realized in a form of an internal combustion engine on which the spark plug is mounted or similar form.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of an exemplary spark plug.

FIG. **2** is an explanatory diagram of a cross section including a central axis CL of a resistor element **70** and a target region A**10** on the cross section.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A. Embodiment

FIG. **1** is a sectional view of an exemplary spark plug according to a first embodiment. The line CL shown in the drawing denotes the central axis of a spark plug **100**. The cross section shown in the drawing is a cross section including a central axis CL. Hereinafter, the central axis CL is also referred to as an "axial line CL" and the direction parallel to the central axis CL is also referred to as an "axial direction." The radial direction of the circle around the central axis CL is also referred to simply as a "radial direction" and the direction of the circumference of the circle around the central axis CL is also referred to as a "circumferential direction." Among directions parallel to the central axis CL, the downward direction in FIG. **1** is referred

to as a front end direction D**1** while the upward direction is also referred to as a rear end direction D**1**_r_. The front end direction D**1** is the direction from a terminal metal fitting **40** toward electrodes **20** and **30** describe later. The front end direction D**1** side in FIG. **1** is referred to as the front end side of the spark plug **100**. The rear end direction D**1**_r_ side in FIG. **1** is referred to as the rear end side of the spark plug **100**.

The spark plug **100** includes an insulator **10** (hereinafter referred to also as a "ceramic insulator **10**"), the center electrode **20**, the ground electrode **30**, the terminal metal fitting **40**, a metal shell **50**, a conductive first seal portion **60**, a resistor element **70**, a conductive second seal portion **80**, a front-end-side packing **8**, a talc **9**, a first rear-end-side packing **6**, and a second rear-end-side packing **7**.

The insulator **10** is an approximately cylindrically-shaped member with a through hole **12** (hereinafter referred to also as a "shaft hole **12**"). The through hole **12** extends along the central axis CL so as to pass through the insulator **10**. The insulator **10** is formed by sintering alumina (another insulating material can also be adopted). The insulator **10** includes a nose portion **13**, a first outer-diameter contracted portion **15**, a front-end-side trunk portion **17**, a flange portion **19**, a second outer-diameter contracted portion **11**, and a rear-end-side trunk portion **18** that are arranged from the front end side toward the rear end direction D**1**_r_ in this order. The outer diameter of the first outer-diameter contracted portion **15** gradually decreases from the rear end side toward the front end side. In the vicinity (the front-end-side trunk portion **17** in the example of FIG. **1**) of the first outer-diameter contracted portion **15** of the insulator **10**, an inner-diameter contracted portion **16** is formed. The inner diameter of the inner-diameter contracted portion **16** gradually decreases from the rear end side toward the front end side. The outer diameter of the second outer-diameter contracted portion **11** gradually decreases from the front end side toward the rear end side.

Into the front end side of the shaft hole **12** of the insulator **10**, a rod-shaped center electrode **20** is inserted. The center electrode **20** extends along the central axis CL. The center electrode **20** includes a nose portion **25**, a flange portion **24**, and a head **23** that are arranged from the front end side toward the rear end direction D**1**_r_ in this order. The portion on the front end side of the nose portion **25** is exposed to the outside of the shaft hole **12** on the front end side of the insulator **10**. The surface on the front end direction D**1** side of the flange portion **24** is supported by the inner-diameter contracted portion **16** of the insulator **10**. The center electrode **20** includes an outer layer **21** and a core portion **22**. The rear end portion of the core portion **22** is exposed from the outer layer **21** so as to form the rear end portion of the center electrode **20**. The other portion of the core portion **22** is coated with the outer layer **21**. However, the entire core portion **22** may be covered with the outer layer **21**.

The outer layer **21** is formed using a material excellent in oxidation resistance compared with the core portion **22**, that is, a material with little wear in the case where the material is exposed to a combustion gas within the combustion chamber of the internal combustion engine. The material of the outer layer **21** employs, for example, nickel (Ni) or an alloy (for example, Inconel ("INCONEL" is a registered trademark)) containing nickel as a main component. Here, the "main component" means the component at the highest content rate (the same shall apply hereafter). As the content rate, the value expressed by weight percent (wt %) is adopted. The core portion **22** is formed using a material with a thermal conductivity higher than that of the outer layer **21**, for example, a material (for example, pure copper or an alloy containing copper as a main component) containing copper.

Into the rear end side of the shaft hole **12** of the insulator **10**, a part of the terminal metal fitting **40** is inserted. The terminal metal fitting **40** is formed using a conductive material (for example, metal such as low-carbon steel). Within the shaft hole **12** of the insulator **10**, the approximately cylindrically-shaped resistor element **70** is arranged between the terminal metal fitting **40** and the center electrode **20**. The resistor element **70** is for reducing electrical noise. The resistor element **70** is formed using a material containing a conductive material (for example, carbon particles), first type particles (for example, SiO_2—B_2O_3—Li_2O—BaO-based glass particles or similar glass particle) with relatively large diameters, and second type particles (for example, ZrO_2 particles and TiO_2 particles) with relatively small diameters. In the drawing, a resistor element diameter **70**D is the outer diameter of the resistor element **70**. In this embodiment, the resistor element diameter **70**D is the same as the inner diameter of the portion that houses the resistor element **70** in the through hole **12** of the insulator **10**.

Within the through hole **12** of the insulator **10**, the conductive first seal portion **60** is arranged between the resistor element **70** and the center electrode **20**. Between the resistor element **70** and the terminal metal fitting **40**, the conductive second seal portion **80** is arranged. The seal portions **60** and **80** are formed using, for example, materials containing the glass particles that are the same as those contained in the material of the resistor element **70** and containing metal particles (for example, Cu).

The center electrode **20** and the terminal metal fitting **40** are electrically connected to each other via the resistor element **70** and the seal portions **60** and **80**. Hereinafter, the entire member (here, the plurality of members **60**, **70**, and **80**) that electrically connects the center electrode **20** and the terminal metal fitting **40** together within the through hole **12** is referred to as a connecting portion **300**. In the drawing, a connecting portion length **300**L is a distance in the direction parallel to the central axis CL between the rear end (the end on the rear end direction D**1***r* side) of the center electrode **20** and the front end (the end on the front end direction D**1** side) of the terminal metal fitting **40**.

The metal shell **50** is an approximately cylindrically-shaped member with a through hole **59**, which extends along the central axis CL so as to pass through the metal shell **50**, (in this embodiment, the central axis of the metal shell **50** coincides with the central axis CL of the spark plug **100**). The metal shell **50** is formed using a low-carbon steel material (or another conductive material (for example, a metallic material) can also be adopted). The insulator **10** is inserted into the through hole **59** of the metal shell **50**. The metal shell **50** is secured to the outer periphery of the insulator **10**. On the front end side of the metal shell **50**, the front end (in this embodiment, the portion on the front end side of the nose portion **13**) of the insulator **10** is exposed to the outside of the through hole **59**. On the rear end side of the metal shell **50**, the rear end (in this embodiment, the portion on the rear end side of the rear-end-side trunk portion **18**) of the insulator **10** is exposed to the outside of the through hole **59**.

The metal shell **50** includes a trunk portion **55**, a seat portion **54**, a deformed portion **58**, a tool engagement portion **51**, and a crimp portion **53** that are arranged from the front end side toward the rear end side in this order. The seat portion **54** is a flanged portion. On the outer peripheral surface of the trunk portion **55**, a screw portion **52** is formed to be threadably mounted on the mounting hole of the internal combustion engine (for example, a gasoline engine). Between the seat portion **54** and the screw portion **52**, an annular gasket **5** is fitted. The gasket **5** is formed by folding a metal plate.

The metal shell **50** includes an inner-diameter contracted portion **56** arranged on the front end direction D**1** side with respect to the deformed portion **58**. The inner diameter of the inner-diameter contracted portion **56** gradually decreases from the rear end side toward the front end side. Between the inner-diameter contracted portion **56** of the metal shell **50** and the first outer-diameter contracted portion **15** of the insulator **10**, the front-end-side packing **8** is sandwiched. The front-end-side packing **8** is made of steel, and is an O-shaped ring (another material (for example, metallic material such as copper) can also be adopted).

The shape of the tool engagement portion **51** is a shape (for example, a hexagonal prism) with which a spark plug wrench is engaged. On the rear end side of the tool engagement portion **51**, the crimp portion **53** is disposed. The crimp portion **53** is arranged on the rear end side with respect to the second outer-diameter contracted portion **11** of the insulator **10** so as to form the rear end (that is, the end on the rear end direction D**1***r* side) of the metal shell **50**. The crimp portion **53** is flexed to radially inside. On the front end direction D**1** side of the crimp portion **53**, the first rear-end-side packing **6**, the talc **9**, and the second rear-end-side packing **7** are arranged in this order toward the front end direction D**1** between the inner peripheral surface of the metal shell **50** and the outer peripheral surface of the insulator **10**. In this embodiment, these rear-end-side packings **6** and **7** are C-shaped rings made of steel (another material can also be adopted).

During manufacture of the spark plug **100**, the crimp portion **53** is crimped so as to be folded to the inside. Then, the crimp portion **53** is pressed toward the front end direction D**1** side. Accordingly, the deformed portion **58** deforms, and the insulator **10** is pressed toward the front end side via the packings **6** and **7** and the talc **9** within the metal shell **50**. The front-end-side packing **8** is pressed between the first outer-diameter contracted portion **15** and the inner-diameter contracted portion **56** so as to seal the gap between the metal shell **50** and the insulator **10**. With the above-described configuration, the metal shell **50** is secured to the insulator **10**.

The ground electrode **30** is sealed to the front end (that is, the end on the front end direction D**1** side) of the metal shell **50**. In this embodiment, the ground electrode **30** is a rod-shaped electrode. The ground electrode **30** extends from the metal shell **50** toward the front end direction D**1**, is bent toward the central axis CL, and reaches a front end portion **31**. The front end portion **31** forms a gap g with a front end surface **29** (the surface **29** on the front end direction D**1** side) of the center electrode **20**. The ground electrode **30** is sealed to the metal shell **50** to be electrically conductive (for example, by laser beam welding). The ground electrode **30** includes a base material **35** and a core portion **36**. The base material **35** forms the surface of the ground electrode **30**. The core portion **36** is buried within the base material **35**. The base material **35** is formed, for example, using Inconel. The core portion **36** is formed using a material (for example, pure copper) with a higher thermal conductivity than that of the base material **35**.

As the method for manufacturing this spark plug **100**, any method can be adopted. For example, the following manufacturing method can be adopted. Firstly, the insulator **10**, the center electrode **20**, the terminal metal fitting **40**, the metal shell **50**, and the rod-shaped ground electrode **30** are manufactured by a well-known method. Additionally, the respective material powders of the seal portions **60** and **80** and material powders of the resistor element **70** are prepared.

In the case where the powder material of the resistor element **70** is prepared, firstly, a conductive material, the second type particles (for example, ZrO_2 particles and TiO_2 particles), which have larger diameters than the diameters of the particles of the conductive material, and a binder are mixed together. As the conductive material, for example, carbon particles such as carbon black can be adopted. As the binder, for example, a dispersant such as polycarboxylic acid can be adopted. To these materials, water is added as solvent. The added materials are mixed using wet ball mill. Then, the mixture is used to generate particles by a spray drying method. Subsequently, the particles of the mixture and the first type particles (for example, glass particles), which have larger diameters than the diameters of the second type particles, are mixed together with the addition of water. Then, drying the obtained mixture causes generation of the powder material of the resistor element **70**. Thus, since the second type particles to which the conductive material is attached are mixed with the first type particles, the conductive material can be dispersed compared with the case where the conductive material is directly mixed with the first type particles.

Subsequently, the center electrode **20** is inserted from an opening (hereinafter referred to as a "rear opening **14**") on the rear end direction D**1***r* side of the through hole **12** of the insulator **10**. As described in FIG. **1**, the center electrode **20** is supported by the inner-diameter contracted portion **16** of the insulator **10** so as to be arranged in a predetermined position within the through hole **12**.

Subsequently, an input of the respective material powders of the first seal portion **60**, the resistor element **70**, and the second seal portion **80** and shaping of the input powder materials are performed in the order corresponding to the members **60**, **70**, and **80**. The powder material is input from the rear opening **14** of the through hole **12**. The input powder material is shaped using a rod inserted from the rear opening **14**. The material powders are shaped into approximately the same shape as the shape of the corresponding member.

Subsequently, the insulator **10** is heated up to a predetermined temperature higher than the softening temperature of the glass component included in the respective material powders. In the state heated up to the predetermined temperature, the terminal metal fitting **40** is inserted into the through hole **12** from the rear opening **14** of the through hole **12**. As a result, the respective material powders are compressed and sintered so as to form each of the seal portions **60** and **80** and the resistor element **70**.

Subsequently, the metal shell **50** is assembled to the outer periphery of the insulator **10** so as to secure the ground electrode **30** to the metal shell **50**. Subsequently, the ground electrode **30** is flexed so as to complete a spark plug.

B. First Evaluation Test

B-1. Outline of First Evaluation Test

In a first evaluation test, a sample of the spark plug **100** of the embodiment was used to evaluate the suppression performance of the radio wave noise and the load life. Table 1 below shows the relationship between the number for the type of the sample, a first type line number NL**1**, a component ratio R (Ti/Zr), a second type line number NL**2**, an average value NcpA of a longitudinal maximum consecutive number Ncp, the connecting portion length **300**L (in the unit of mm), the resistor element diameter **70**D (in the unit of mm), the evaluation result (hereinafter referred to as a "radio-wave-noise evaluation result") of the suppression performance of the radio wave noise, and the evaluation result of the load life. In this evaluation test, the samples of 23 types from No. **1** to No. **23** were evaluated.

TABLE 1

No.	First Type Line Number NL1 (Nc ≥ 2)	Component Ratio R (Ti/Zr)	Second Type Line Number NL2 (Ncc ≥ 2)	Average Value NcpA of Longitudinal Maximum Consecutive Number Ncp	Connecting Portion Length 300L	Resistor Element Diameter 70D	Radio-Wave-Noise Evaluation Result	Load-Life Evaluation Result
1	1	1	0	3.0	11	3.5	2	2
2	5	1	3	1.9	11	3.5	4	6
3	5	1	5	1.8	11	3.5	4	9
4	7	1	3	2.1	11	3.5	4	6
5	7	1	5	2.0	11	3.5	4	9
6	8	1	6	2.1	11	3.5	4	9
7	10	1	7	3.1	11	3.5	4	10
8	12	1	10	3.3	11	3.5	5	10
9	12	1	10	5.0	11	3.5	5	10
10	12	1	10	6.0	11	3.5	4	9
11	12	0	10	3.2	11	3.5	5	7
12	12	0.05	10	3.3	11	3.5	5	8
13	12	0.5	10	3.0	11	3.5	5	10
14	12	2	10	3.1	11	3.5	5	10
15	12	3	10	2.8	11	3.5	5	10
16	12	6	10	2.7	11	3.5	4	10
17	12	10	10	2.7	11	3.5	3	10
18	1	1	0	0.9	11	4	1	3
19	10	1	7	3.1	11	4	4	10
20	1	1	0	0.8	11	2.9	3	1
21	10	1	7	3.0	11	2.9	5	10
22	1	1	0	0.8	15	3.5	3	1
23	10	1	7	3.0	15	3.5	5	10

The line numbers NL**1** and NL**2** and the average value NcpA are specified based on the analysis result of the cross section of the resistor element **70** (details will be described below). The component ratio R is the proportion (weight proportion) of the amount of a Ti element to the amount of a Zr element in the resistor element **70** (that is, a filler). This proportion was specified by scraping off a part of the resistor element **70** and analyzing the scraped portion using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP emission spectroscopy). Here, the material of the resistor element **70** of each sample employed the material that contained carbon black as the conductive material, SiO_2—B_2O_3—Li_2O—BaO-based glass particles as the first type particles, and ZrO_2 particles and TiO_2 particles as the second type particles.

The radio-wave-noise evaluation result was determined using the attenuation of the radio wave noise. The attenuation was measured in accordance with the box method specified by JASO D002-2 (2004). Specifically, for each sample number, five samples with the same configuration were manufactured. In the configuration, the resistance value was within a range of 1.40±0.05 (kΩ). Then, the average values of the attenuations of the five samples at 300 MHz were used to determine the evaluation values. The evaluation value was calculated by adding 1 point for each increase of 0.1 dB in improved value of the average attenuation compared with the reference. The average attenuation of the sample No. **16** was set to the reference (1 point). For example, in the case where the improved value from the average attenuation of No. **16** is equal to or more than 0.1 dB and less than 0.2 dB, the radio-wave-noise evaluation result is 2 points.

The load life denotes the durability against discharging. To evaluate the durability, for each sample number, five samples with the same configuration were manufactured. In the configuration, the resistance value was within a range of 1.40±0.05 (kΩ). The manufactured sample was manufactured under the same conditions as those of the sample with the same number used for evaluation of the suppression performance of the radio wave noise. Then, the sample was connected to a power source so as to perform an operation for repeating a multiple discharge under the following conditions. The following conditions are conditions severer than general usage conditions.

Temperature: 400 degrees Celsius

Discharge Cycle: 60 Hz

Energy Output from Power Source in 1 Cycle: 400 mJ

In the evaluation test, the operation was performed under the above-described conditions. After the operation, the electric resistance value at ordinary temperature between the center electrode **20** and the terminal metal fitting **40** was measured. The operation and the measurement of the electric resistance value were repeated until the electric resistance value of at least one sample of the five samples after the operation was increased up to a value that was 1.5 times or more larger than the electric resistance value before the evaluation test. Then, the evaluation result was determined as follows based on the total operating period when the electric resistance value of at least one sample after the operation had been increased up to a value that was 1.5 times or more larger than the electric resistance value before the evaluation test.

Total Operating Period: Evaluation Result

Less Than 10 hours: 1 point

10 hours Or More, Less Than 20 hours: 2 points

20 hours Or More, Less Than 100 hours: 3 points

100 hours Or More, Less Than 120 hours: 4 points

120 hours Or More, Less Than 140 hours: 5 points

(after that, 1 point is added for each increase of 20 hours in total operating period)

The following describes the line numbers NL**1** and NL**2** shown in Table 1. FIG. **2** is an explanatory diagram of a cross section including the central axis CL in the resistor element **70** and a target region A**10** on the cross section. The left lower portion of FIG. **2** shows the cross section including the central axis CL in the resistor element **70** within the through hole **12**. The target region A**10** is shown on the cross section of the resistor element **70** shown in the drawing. This target region A**10** is a rectangular region that employs the central axis CL (the axial line CL) as the center line. The rectangular shape includes two sides parallel to the central axis CL and two sides perpendicular to the central axis CL. The shape of the target region A**10** is line symmetric with respect to the central axis CL as a symmetry axis. The target region A**10** is arranged not to protrude from the resistor element **70**. Here, as shown in the drawing, the end face on the front end direction D**1** side and the end face on the rear end direction D**1***r* side of the resistor element **70** might be curved. A resistor element length **70**L in the drawing is the length in the direction parallel to the central axis CL in the resistor element **70**. The resistor element length **70**L corresponds to the length of the portion whose entire region surrounded by the inner peripheral surface of the insulator **10** is occupied by the resistor element **70** in the cross section perpendicular to the central axis CL.

The right side portion of FIG. **2** shows an enlarged diagram of the target region A**10**. A first length La is a length in the direction perpendicular to the central axis CL of the target region A**10**. A second length Lb is a length in the direction parallel to the central axis CL of the target region A**10**. Here, the first length La is 1800 μm while the second length Lb is 2400 μm.

As shown in the drawing, the target region A**10** is divided into a plurality of square regions A**20**. In the square region A**20**, a length Ls of one side is 200 μm. Accordingly, within the target region A**10**, the number of the square regions A**20** in the direction parallel to the central axis CL is 12 while the number of the square regions A**20** in the direction perpendicular to the central axis CL is 9. Hereinafter, the line-shaped region constituted of the nine square regions A**20** arranged in the direction perpendicular to the central axis CL is referred to as a transverse line-shaped region. The line-shaped region constituted of the 12 square regions A**20** arranged in the direction parallel to the central axis CL is referred to as the longitudinal line-shaped region. As shown in FIG. **2**, the target region A**10** is divided into 12 transverse line-shaped regions L**01** to L**12** arranged toward the front end direction D**1**. Additionally, the target region A**10** is divided into nine longitudinal line-shaped regions L**21** to L**29** arranged toward the direction perpendicular to the central axis CL.

In the top-left portion of FIG. **2**, a partial cross section **400** is shown. The partial cross section **400** includes one square region A**20**. This partial cross section **400** shows a part of the cross section of the resistor element **70**. As shown in the drawing, the cross section includes aggregate regions Aa and conductive regions Ac sandwiched between the aggregate regions Aa. The aggregate region Aa is hatched with a relatively dark color while the conductive region Ac is hatched with a relatively light color.

The aggregate region Aa is mainly formed of the first type particles (here, glass particles). The aggregate region Aa includes a relatively large particulate portion (for example, a portion Pg in the drawing). This particulate portion Pg is formed of glass particles. Hereinafter, the particulate portion with the maximum particle diameter of 20 μm or more in the resistor element **70** is referred to as the "aggregate." In the sample evaluated in the evaluation test, the portion formed of glass particles (for example, the portion Pg) corresponds to the aggregate.

The conductive region Ac is mainly formed of the second type particle (here, ZrO_2 and TiO_2) and the conductive material (here, carbon). Above the partial cross section **400** in the drawing, a partial enlarged diagram **400***c* of the conductive region Ac is shown. As shown in the drawing, the conductive region Ac includes a zirconia portion P**1**, which is a portion formed of ZrO_2, a titania portion P**2**, which is formed of TiO_2, and another component portion P**3**, which is formed of another component (for example, glass melted during manufacture). In the drawing, the titania portion P**2** and the other component portion P**3** are hatched.

In the cross section, the zirconia portion P**1** and the titania portion P**2** form particulate regions. Hereinafter, the particulate portion with the maximum particle diameter of less than 20 μm in the resistor element **70** is referred to as the "filler." In the sample evaluated in the evaluation test, the filler of the resistor element **70** includes the zirconia portion P**1** and the titania portion P**2**. Here, the ZrO_2 material powder, which was the material of the zirconia portion P**1**, had the average grain diameter of 3 μm. The TiO_2 material powder, which was the material of the titania portion P**2**, had the average grain diameter of 5 μm. In the completed resistor element **70**, the average grain diameter of the zirconia portion P**1** and the average grain diameter of the titania portion P**2** are approximately the same as the average grain diameters of the respective material powders.

As described above, the conductive material (here, carbon) is dispersed in the state attached to the filler (for example, the ZrO_2 particle). Accordingly, the conductive material is distributed in the zirconia portion P**1** and its vicinity, that is, in the conductive region Ac. The conductive region Ac achieves the conductive property using the conductive material. Thus, it can be said that the zirconia portion P**1** shows the current path in the resistor element **70**. In other words, during discharge, a current does not flow in the aggregate region Aa but mainly flows in the zirconia portion P**1** and its vicinity.

To specify the line numbers NL**1** and NL**2** and the average value NcpA in Table 1, the zirconia portion P**1** within the target region A**10** was specified. The zirconia portion P**1** was specified by analyzing the ZrO_2 distribution within the target region A**10** using a scanning electron microscope/an energy-dispersive X-ray spectrometer (SEM/EDS). As the analyzer, JSM-6490LA made by JEOL Ltd. was used. For the analysis, the sample of the spark plug **100** was cut along the plane including the central axis CL, and then the cross section of the resistor element **70** was mirror polished. As the sample, the samples manufactured under the same conditions as the samples used in the evaluation of the suppression performance of the radio wave noise and the evaluation of the load life were used. The mirror polished cross section was analyzed using the analyzer. Here, the accelerating voltage was set to 20 kV and the number of sweeps was set to 50. Then, EDS mapping was performed. The result of the EDS mapping was saved as black-and-white (that is, binary) bit-mapped image data. At this time, through the operation menu of "Tools-Histogram" in the analysis tool of the analyzer, setting of the threshold in the black-and-white image was performed. In the setting, the value equal to or more than 20% of the maximum value was set to white while the value less than 20% was set to black. In the image thus obtained, the white region was adopted as the zirconia portion P**1**.

Here, in the case where the threshold is set, the integer obtained by rounding the value of 20% of the maximum value to the nearest whole number was adopted as the threshold upper limit. The value obtained by subtracting the threshold upper limit from 1 was adopted as the threshold lower limit Setting the threshold lower limit to the value obtained by subtracting the threshold upper limit from 1 allows black and white binarization without generating the portion with the intermediate color (gray) between black and white. For example, in the case where the maximum value is 35, the threshold upper limit is set to 7 (35×20%) and the threshold lower limit is set to 6. In this case, a region with a value equal to or more than 7 is categorized into a white region and a region with a value less than 7 is categorized into a black region. Also in the case where the maximum value is 37, the threshold upper limit is set to 7 and the threshold lower limit is set to 6 similarly. In the case where the maximum value is 38, the threshold upper limit is set to 8 and the threshold lower limit is set to 7.

The first type line number NL**1** in Table 1 was determined using the zirconia portion P**1** thus specified. Specifically, for each of the 108 square regions A**20** included in the target region A**10**, the proportion of the area of the zirconia portion P**1** was calculated. Then, the square region A**20** where the area proportion of the zirconia portion P**1** was equal to or more than 25% was categorized into a first type region A**1**. The square region A**20** where the area proportion of the zirconia portion P**1** was less than 25% was categorized into a second type region A**2**. In the example of FIG. **2**, the second type region A**2** is hatched. In the drawing, a first type region number Nc shown on the right side of the target region A**10** denotes the number of the first type regions A**1** included in each transverse line-shaped region. For example, the first type region number Nc of the second transverse line-shaped region L**02** is 2. As described above, the zirconia portion P**1** is likely to cause a current flow compared with the aggregate region Aa. Accordingly, the large first type region number Nc shows that the current is likely to flow along that transverse line-shaped region, that is, in the direction intersecting with the central axis CL.

The first type line number NL**1** in Table 1 is the number of transverse line-shaped regions (hereinafter referred to as "first type lines") with the first type region number Nc of 2 or more. The large first type line number NL**1** means that the current is likely to flow through the respective many transverse line-shaped regions (for example, NL**1** lines of the transverse line-shaped regions) along the extending directions of the respective transverse line-shaped regions. Accordingly, in the case where the first type line number NL**1** is large, the current flowing through the resistor element **70** can pass through a complicated path passing through a plurality of transverse line-shaped regions. In the case where the current passes through the complicated path, the radio wave noise can be reduced compared with the case where the current passes through a straight path parallel to the central axis CL. The effect for reducing the radio wave noise is estimated to be larger as the shape of the path becomes more complicated, that is, the first type line number NL**1** becomes larger. Additionally, in the case where the current passes through the complicated path, the current can be dispersed within the resistor element **70** compared with the case where the current passes through a straight path parallel to the central axis CL. Accordingly, a local deterioration of the resistor element **70** is estimated to be reduced as the first type line number NL**1** becomes larger.

In FIG. **2**, the first type region number Nc of 2 or more is enclosed in a square. In the example of FIG. **2**, the number of lines with the first type region numbers Nc of 2 or more, that is, the first type line number NL**1** is 10 lines.

The second type line number NL**2** in Table 1 was determined using a transverse maximum consecutive number Ncc shown next to the first type region number Nc in FIG. **2**. When the portion including the consecutive first type regions A1 within one transverse line-shaped region is referred to as a transverse consecutive portion, the transverse maximum consecutive number Ncc is the maximum value of the number of the first type regions A1 included in one transverse consecutive portion. In FIG. 2, the transverse consecutive portion is shown by the double line. For example, the transverse maximum consecutive number Ncc of the fourth transverse line-shaped region L04 is 2. The large transverse maximum consecutive number Ncc shows that the current is more likely to flow along that transverse line-shaped region.

The second type line number NL2 in Table 1 is the number of transverse line-shaped regions (hereinafter referred to also as "second type lines") with the transverse maximum consecutive number Ncc of 2 or more. The large second type line number NL2 means that the current is more likely to flow through the respective many transverse line-shaped regions (for example, NL2 lines of the transverse line-shaped regions) along the extending directions of the respective transverse line-shaped regions. Accordingly, in the case where the second type line number NL2 is large, the current flowing through the resistor element 70 is likely to pass through a complicated path passing through a plurality of transverse line-shaped regions. This allows further reducing the radio wave noise. The effect for reducing the radio wave noise is estimated to be larger as the shape of the path becomes more complicated, that is, the second type line number NL2 becomes larger. Additionally, in the case where the current passes through the complicated path, the current can be dispersed within the resistor element 70 compared with the case where the current passes through a straight path parallel to the central axis CL. Accordingly, a local deterioration of the resistor element 70 is estimated to be reduced as the second type line number NL2 becomes larger.

In FIG. 2, the transverse maximum consecutive number Ncc of 2 or more is enclosed in a square. In the example of FIG. 2, the number of lines with the transverse maximum consecutive numbers Ncc of 2 or more, that is, the second type line number NL2 is 8 lines.

The average value NcpA of the longitudinal maximum consecutive number Ncp in Table 1 is the average value of the respective longitudinal maximum consecutive numbers Ncp of the nine longitudinal line-shaped regions L21 to L29 shown in FIG. 2. When the portion including the consecutive first type regions A1 within one longitudinal line-shaped region is referred to as a longitudinal consecutive portion, the longitudinal maximum consecutive number Ncp is the maximum value of the number of the first type regions A1 included in one longitudinal consecutive portion. In FIG. 2, the longitudinal consecutive portion is shown by the bold line connecting a plurality of the first type regions A1 that forms the longitudinal consecutive portion. For example, the longitudinal maximum consecutive number Ncp of the fourth longitudinal line-shaped region L24 is 3. In the example of FIG. 2, the average value NcpA of the nine longitudinal maximum consecutive number Ncp is 2.1. The large longitudinal maximum consecutive number Ncp shows that the current is likely to flow along that longitudinal line-shaped region.

Here, analySIS Five (trade name) of image analysis software by Soft Imaging System GmbH was used for analysis of the bit-mapped image data, that is, calculation of the area to specify the first type region A1, the second type region A2, and the average value NcpA and calculation of the first type line number NL1, the second type line number NL2, and the average value NcpA. Additionally, the line numbers NL1 and NL2 and the average value NcpA in Table 1 are the average values of the analysis results of the two target region A10 in different positions on the cross section of one sample.

B-2. First Type Line Number NL1 and Evaluation Result:

The respective first type line numbers NL1 of No. 1 to No. 10 in Table 1 were 1, 5, 5, 7, 7, 8, 10, 12, 12, and 12. In these 10 types of samples, the component ratio R had the same value of 1, the connecting portion length 300L had the same value of 11 mm, and the resistor element diameter 70D had the same value of 3.5 mm. The resistor element length 70L (in FIG. 2) was approximately 8 mm.

As shown by No. 1 to No. 10, the radio-wave-noise evaluation result was favorable in the case where the first type line number NL1 was large compared with the case where the first type line number NL1 was small. The evaluation result of the load life was favorable in the case where the first type line number NL1 was large compared with the case where the first type line number NL1 was small. As the reason for these results, it is estimated that this is because the shape of the current path becomes more complicated as the first type line number NL1 becomes larger as described above.

The first type line numbers NL1 that were able to achieve the radio-wave-noise evaluation result more favorable than 2 points and the load-life evaluation result more favorable than 2 points were 5, 7, 8, 10, and 12. Any value selected from these values can be adopted as the lower limit of a preferred range (the lower limit or more and the upper limit or less) of the first type line number NL1. For example, as the first type line number NL1, the value of 5 lines or more can be adopted. Additionally, any value of the lower limit or more among these values can be adopted as the upper limit of the preferred range of the first type line number NL1. For example, as the first type line number NL1, the value of 12 lines or less can be adopted.

Here, from the aspect of improvement of the radio-wave-noise evaluation result, it is estimated that the path of the current flowing within the resistor element 70 is preferred to be thin and complicated in an intricate pattern. However, in the case where the current path is thin, the current path is more likely to be cut due to heat and vibration (that is, the load life is short) compared with the case where the current path is thick. Therefore, in this evaluation test, as described in FIG. 2, the first type region A1 in which the current is relatively likely to flow and the second type region A2 in which the current is relatively less likely to flow were determined using the proportion of the area of the zirconia portion P1 in the square region A20 where one side had the length of 200 μm that was larger than the filler. In this case, in the case where the current path formed by the zirconia portion P1 is excessively thin, the square region A20 is not categorized into the first type region A1. In the case where the current path is thick to some extent, the square region A20 is categorized into the first type region A1. Using this first type region A1 allowed obtaining the parameter correlated with both the radio-wave-noise evaluation result and the load-life evaluation result, that is, the first type line number NL1. Here, in the case where the length of one side of the square region A20 is larger than 200 μm, the line number NL1 is increased even when the current path (for example, a thick current path extending in parallel to the central axis CL) with a small influence on the reduction of the radio wave noise is formed. Accordingly, the correlation between the first type line number NL1 and the radio-wave-noise evaluation result is estimated to become weak. The same applies to the second type line number NL2 described below.

B-3. Second Type Line Number NL**2** and Evaluation Result:

The respective second type line numbers NL**2** of No. **1** to No. **10** in Table 1 were 0, 3, 5, 3, 5, 6, 7, 10, 10, and 10. As shown by these samples, the radio-wave-noise evaluation result and the load-life evaluation result were favorable in the case where the second type line number NL**2** was large compared with the case where the second type line number NL**2** was small. As the reason for these results, it is estimated that this is because the shape of the current path becomes more complicated as the second type line number NL**2** becomes larger as described above.

Here, the second type line numbers NL**2** that were able to achieve the load-life evaluation result more favorable than 2 points were 3, 5, 6, 7, and 10. Any value selected from these values can be adopted as the lower limit of a preferred range (lower limit or more and the upper limit or less) of the second type line number NL**2**. For example, as the second type line number NL**2**, the value of 3 lines or more can be adopted. Additionally, the second type line numbers NL**2** that were able to achieve the load-life evaluation result more favorable than 6 points were 5, 6, 7, and 10. Accordingly, as the second type line number NL**2**, the value of 5 lines or more is preferred to be adopted. Additionally, the best second type line numbers NL**2** that were able to achieve the load-life evaluation result of 10 points were 7 and 10. Accordingly, as the second type line number NL**2**, the value of 7 lines or more is preferred to be adopted. Here, it is estimated that the large second type line number NL**2** achieves a more favorable load-life evaluation result. Accordingly, as the second type line number NL**2**, it is estimated that various values equal to or less than 12 lines, which is the theoretical maximum, can be adopted. Additionally, as the upper limit, any value of the lower limit or more selected from the above-described evaluated values (for example, 3, 5, 6, 7, and 10) can be adopted.

B-4. Component Ratio R (Ti/Zr) and Evaluation Result:

The respective component ratios R (Ti/Zr) of No. **11** to No. **17** in Table 1 were 0, 0.05, 0.5, 2, 3, 6, and 10. In these seven types of samples, the first type line number NL**1** had the same value of 12, the second type line number NL**2** had the same value of 10, the connecting portion length **300**L had the same value of 11 mm, and the resistor element diameter **70**D had the same value of 3.5 mm. The configurations of the samples No. **11** to No. **17** were otherwise similar to the configurations of the samples No. 1 to No. **10**.

As shown by No. **11** to No. **17**, the load-life evaluation result was favorable in the case where the component ratio R was large compared with the case where the component ratio R was small. As the reason for this result, it is estimated that this is because the large proportion of TiO_2 increases the path of the current passing through TiO_2 so as to disperse the current within the resistor element **70**, thus reducing the deterioration of the resistor element **70**. The radio-wave-noise evaluation result was favorable in the case where the component ratio R was small compared with the case where the component ratio R was large. As the reason for this result, it is estimated that this is because the smaller proportion of TiO_2 reduces the path of the current passing through TiO_2, thus complicating the current path within the resistor element **70**.

In addition to No. **11** to No. **17**, taking into consideration No. **1** to No. **10**, the component ratios R that were able to achieve the load-life evaluation results of 8 points or more were 0.05, 0.5, 1, 2, 3, 6, and 10. Additionally, the component ratios R that were able to achieve the radio-wave-noise evaluation result of 4 points or more were 0, 0.05, 0.5, 1, 2, 3, and 6. The component ratios R included in both results were six values of 0.05, 0.5, 1, 2, 3, and 6. Any value selected from these six values can be adopted as the lower limit of a preferred range (the lower limit or more and the upper limit or less) of the component ratio R. In the six values, any values of the lower limit or more can be adopted as the upper limit. For example, as the component ratio R, the value that is 0.05 or more and 6 or less can be adopted. More preferably, as the component ratio R, the value that is 0.5 or more and 6 or less can be adopted. Further preferably, as the component ratio R, the value that is 0.5 or more and 3 or less can be adopted.

Here, the component ratios R of No. **1** to No. **10** was 1, and was larger than the lower limit and smaller than the upper limit of the above-described preferred range of the component ratio R. Additionally, as shown by No. **1** to No. **10**, in the case where the component ratio R was 1, various combinations of the first type line number NL**1** and the second type line number NL**2** were able to achieve the radio-wave-noise evaluation result of 4 points or more and the load-life evaluation result of 8 points or more. Accordingly, it is estimated that the above-described preferred range of the component ratio R is applicable to the case where the first type line number NL**1** is different from 12, which is the first type line number NL**1** of No. **11** to No. **17**. Similarly, the above-described preferred range of the component ratio R is applicable to the case where the second type line number NL**2** is different from 10, which is the second type line number NL**2** of No. **11** to No. **17**.

B-5. Resistor Element Diameter **70**D and Evaluation Result:

The respective resistor element diameters **70**D of No. **18** and No. **19** in Table 1 were 4 mm that was larger than the resistor element diameter **70**D (3.5 mm) of No. **1** to No. **17**. The configuration of No. **18** had NL**1**=1, NL**2**=0, and R=1. The two parameters NL**1** and NL**2** were out of the above-described preferred ranges. For No. **18**, the radio-wave-noise evaluation result was 1 point and the load-life evaluation result was 3 points. On the other hand, the configuration of No. **19** had NL**1**=10, NL**2**=7, and R=1. The respective three parameters NL**1**, NL**2**, and R were within the above-described preferred ranges. The radio-wave-noise evaluation result of No. **19** was 4 points more favorable than that of No. **18**. The load-life evaluation result of No. **19** was 10 points more favorable than that of No. **18**.

The respective resistor element diameters **70**D of No. **20** and No. **21** in Table 1 were 2.9 mm that is smaller than the resistor element diameter **70**D (3.5 mm) of No. **1** to No. 17. The configuration of No. **20** had NL**1**=1, NL**2**=0, and R=1. The two parameters NL**1** and NL**2** were out of the above-described preferred ranges. The radio-wave-noise evaluation result of No. **20** was 3 points and the load-life evaluation result was 1 point. On the other hand, the configuration of No. **21** had NL**1**=10, NL**2**=7, and R=1. The respective three parameters NL**1**, NL**2**, and R were within the above-described preferred ranges. The radio-wave-noise evaluation result of No. **21** was 5 points more favorable than that of No. **20**. The load-life evaluation result of No. **21** was 10 points more favorable than that of No. **20**.

Here, in the samples of No. **18** to No. **21**, the connecting portion length **300**L had the same value of 11 mm. The resistor element length **70**L (in FIG. **2**) had approximately the same value of 8 mm.

Generally, in the case where the resistor element diameter **70**D is small, the surface area of the resistor element **70** is small compared with the case where the resistor element diameter **70**D is large. Accordingly, the heat generated due to the flow of the current through the resistor element **70** is less likely to transfer to the other member such as the insulator **10**. That is, in the case where the resistor element diameter **70**D is small, the load-life evaluation result of the resistor element **70** is likely to be reduced. Additionally, in the case where the resistor element diameter **70**D is small, the length of the current path that extends in the direction intersecting with the central axis CL is restricted to be in a range where the length is short. Accordingly, the suppression performance of the radio wave noise is likely to be reduced. Here, as shown in Table 1, the three resistor element diameters **70**D of 2.9, 3.5, and 4 (mm) were able to achieve the radio-wave-noise evaluation result of 4 points or more and the load-life evaluation result of 8 points or more. Thus, as the resistor element diameter **70**D, the value of 4 mm or less can be adopted, the smaller value of 3.5 mm or less can be adopted, and the further smaller value of 2.9 mm or less can be adopted. Additionally, as the resistor element diameter **70**D, when any value (for example, 2.9 mm) of the upper limit or less among the three values is selected as the lower limit, the value of the lower limit or more can be adopted.

Generally, taking into consideration the fact that the achievement of the radio-wave-noise evaluation result of 2 points or more and the load-life evaluation result of 2 points or more allows practical use, the allowable range of the resistor element diameter **70**D is estimated to be extendable to a wide range including these three values of (2.9, 3.5, and 4 (mm)) For example, as the resistor element diameter **70**D, it is estimated that various values equal to or more than 1.8 mm, which is the first length La of the target region A**10**, can be adopted. Additionally, taking into consideration the practical size of the spark plug **100**, it is estimated that various values of 6 mm or less can be adopted as the resistor element diameter **70**D. In each case, it is estimated that setting at least the first type line number NL**1** within the above-described preferred range allows achieving the favorable radio-wave-noise evaluation result (for example, 2 points or more) and the favorable load-life evaluation result (for example, 2 points or more). Here, in addition to the first type line number NL**1**, the second type line number NL**2** is preferred to be set within the above-described preferred range. Additionally, the component ratio R is preferred to be set within the above-described preferred range.

B-6. Connecting Portion Length **300**L and Evaluation Result:

The respective connecting portion lengths **300**L of No. **22** and No. **23** in Table 1 were 15 mm that was larger than the connecting portion length **300**L (11 mm) of No. **1** to No. **21**. The connecting portion length **300**L of 15 mm was achieved by moving the position of the front end (the end on the front end direction D**1** side) of the terminal metal fitting **40** toward the rear end direction D**1***r* side and then lengthening the length (specifically, the resistor element length **70**L in FIG. **2**) in the direction parallel to the central axis CL of the resistor element **70**. The shape and the size of the first seal portion **60** were approximately the same as those in all the samples No. **1** to No. **21**. Similarly, the shape and the size of the second seal portion **80** were approximately the same as those in all the samples No. **1** to No. **21**.

The configuration of No. **22** had NL**1**=1, NL**2**=0, R=1, and **70**D=3.5 mm. The two parameters NL**1** and NL**2** were out of the above-described preferred ranges. For No. **22**, the radio-wave-noise evaluation result was 3 points and the load-life evaluation result was 1 point. On the other hand, the configuration of No. **23** had NL**1**=10, NL**2**=7, R=1, and **70**D=3.5 mm. The respective four parameters NL**1**, NL**2**, R, and **70**D were within the above-described preferred ranges. The radio-wave-noise evaluation result of No. **23** was 5 points more favorable than that of No. **22**. The load-life evaluation result of No. **23** was 10 points more favorable than that of No. **22**.

Generally, in the case where the connecting portion length **300**L is long, the manufacture of the connecting portion **300** (including the resistor element **70**) is difficult compared with the case where the connecting portion length **300**L is short. For example, there is the case where the material of the connecting portion **300** (for example, the resistor element **70**) arranged within the through hole **12** is compressed using the rod inserted from the rear opening **14** of the through hole **12**. In the case where the connecting portion length **300**L is long, the pressure for compression is likely to be dispersed in the course of the connecting portion **300**. As a result, the suppression performance of the radio wave noise might be reduced and the durability might be reduced without appropriate compression of the material of the resistor element **70**. Here, as shown in Table 1, the two connecting portion lengths **300**L of 11 mm and 15 mm achieved the radio-wave-noise evaluation result of 4 points or more and the load-life evaluation result of 8 points or more. Thus, as the connecting portion length **300**L, the value of 11 mm or more can be adopted and the longer value of 15 mm or more can be adopted. Additionally, as the connecting portion length **300**L, when any value (for example, 15 mm) of the lower limit or more among the two values is selected as the upper limit, the value of the upper limit or less can be adopted.

Generally, taking into consideration the fact that the achievement of the radio-wave-noise evaluation result of 2 points or more and the load-life evaluation result of 2 points or more allows practical use, the allowable range of the connecting portion length **300**L is estimated to be extendable to a wide range including these two value (11 and 15 (mm)) For example, as the connecting portion length **300**L, it is estimated that various values of 5 mm or more can be adopted. Additionally, as the connecting portion length **300**L, it is estimated that various values of 30 mm or less can be adopted. In each case, it is estimated that setting at least the first type line number NL**1** within the above-described preferred range allows achieving the favorable radio-wave-noise evaluation result (for example, two points or more) and the favorable load-life evaluation result (for example, two points or more). Here, in addition to the first type line number NL**1**, the second type line number NL**2** is preferred to be set within the above-described preferred range. Additionally, the component ratio R is preferred to be set within the above-described preferred range. Additionally, the resistor element diameter **70**D is preferred to be set within the above-described allowable range.

B-7. Average Value NcpA of Longitudinal Maximum Consecutive Number Ncp and Evaluation Result:

According to No. **1** to No. **23** in Table 1, the average values NcpA that were able to achieve the radio-wave-noise evaluation result of 2 points or more were 13 values of 0.8, 1.8, 1.9, 2.0, 2.1, 2.7, 2.8, 3.0, 3.1, 3.2, 3.3, 5.0, and 6.0. Any value selected from these 13 values can be adopted as the lower limit of a preferred range (the lower limit or more and the upper limit or less) of the average value NcpA. Any value of the lower limit or more in the 13 values can be adopted as the upper limit Here, it is estimated that the smaller average value NcpA complicates the current path. Accordingly, as the average value NcpA, it is estimated that the value (for example, various values of zero or more) smaller than the minimum value (0.8) in the above-described 13 values can be adopted. For example, as the average value NcpA, it is estimated that the value that is zero or more and 6.0 or less can be adopted. However, it is estimated that setting the first type line number NL**1** within the above-described preferred range causes the average value NcpA of the longitudinal maximum consecutive number Ncp to be also a value larger than zero.

As shown by No. **10** and the other samples, in the case where the average value NcpA is 5.0 or less, the various average values NcpA were able to achieve the radio-wave-noise evaluation result of 5 points. In the case where the average value NcpA was 6.0, the radio-wave-noise evaluation result was 4 points lower than that point. As the reason for this result, it is estimated that this is because an increase in average value NcpA is likely to cause the current to flow along the longitudinal line-shaped region, thus simplifying the current path as a result. With the above-described results, it is estimated that adopting the value of 5.0 or less as the average value NcpA of the longitudinal maximum consecutive number Ncp allows achieving the more favorable radio-wave-noise evaluation result.

In each case, it is estimated that setting at least the first type line number NL**1** within the above-described preferred range allows achieving the favorable radio-wave-noise evaluation result (for example, 2 points or more) and the favorable load-life evaluation result (for example, 2 points or more). Here, in addition to the first type line number NL**1**, the second type line number NL**2** is preferred to be set within the above-described preferred range. Additionally, the component ratio R is preferred to be set within the above-described preferred range. Additionally, the resistor element diameter **70**D is preferred to be set within the above-described allowable range. Additionally, the connecting portion length **300**L is preferred to be set within the above-described allowable range.

C. Second Evaluation Test

C-1. Outline of Second Evaluation Test:

In the second evaluation test, the relationship between the configuration, the suppression performance of the radio wave noise, and the load life for samples of the spark plug **100** according to the embodiment was evaluated. Table 2 below shows, regarding the samples, the relationship between the number for type, the first type line number NL**1**, the component ratio R (Ti/Zr), the second type line number NL**2**, a first type region proportion RAL a first-type-region-number expected value NcE, a transverse-maximum-consecutive-number expected value NccE, a determination result of continuity, a transverse-maximum-consecutive-number average value NccA, the connecting portion length **300**L (in the unit of mm), the resistor element diameter **70**D (in the unit of mm), the radio-wave-noise evaluation result, and the load-life evaluation result. In the second evaluation test, five types of samples No. T**1** to No. T**5** were evaluated.

TABLE 2

							Transverse Line-Shaped Region					
[Table 2] No.	First Type Line Number NL1 (Nc ≥ 2)	Component Ratio R (Ti/Zr)	Second Type Line Number NL2 (Ncc ≥ 2)	First Type Region Proportion RA1	First-Type-Region-Number Expected Value NcE	Transverse-Maximum-Consecutive-Number Expected Value NccE	Continuity Judgment Result	Transverse-Maximum-Consecutive-Number Average Value NccA	Connecting Portion Length 300L	Resistor Element Diameter 70D	Radio-Wave-Noise Evaluation Result	Load-Life Evaluation Result
T1	12	1	12	0.935 (101/108)	8	6.2	A	7.33	11	3.5	5	10
T2	6	1	6	0.324 (35/108)	3	1.67	A	1.83	11	3.5	5	10
T3	10	1	8	0.343 (37/108)	3	1.67	A	1.75	11	3.5	5	10
T4	12	1	10	0.454 (49/108)	4	2.21	A	2.50	11	3.5	5	10
T5	12	1	10	0.454 (49/108)	4	2.21	B	2.18	11	3.5	5	5

The respective parameters NL**1**, R, NL**2**, **300**L, and **70**D in Table 2 are the same as the parameters with the same reference numerals in Table 1. The radio-wave-noise evaluation result was determined by the same method as the method of the first evaluation test in Table 1. The load-life evaluation result was determined by the method where "Energy Output from Power Source in 1 Cycle" was changed to 600 mJ larger than 400 mJ in the method of the first evaluation test in Table 1. That is, in the second evaluation test, the load life was evaluated under conditions severer than those of the first evaluation test.

The following describes other parameters in Table 2. The first type region proportion RA**1** is the proportion of the total number of the first type regions A**1** to the total number of the square regions A**20** in the target region A**10** (in FIG. **2**). As described above, the total number of the square region A**20** is 108. In brackets of the column of the first type region proportion RA**1** in Table 2, "108" as the total number of the square regions A**20** and also the total number of the first type regions A**1** are shown. For example, the total number of the first type region A**1** in No. T**1** is 101.

The first-type-region-number expected value NcE is the expected value of the first type region number Nc (that is, the number of the first type regions A**1** included in one transverse line-shaped region). This first-type-region-number expected value NcE is calculated by INT (9*RA**1**). Here, the function "INT" denotes the function that rounds an argument to the nearest whole number as an integer. The operation symbol "*" denotes multiplication (the same shall apply hereafter). The value "9" is the total number of the square regions A**20** included in one transverse line-shaped region. The first-type-region-number expected value NcE thus calculated denotes the total number of the first type regions A**1** included in one transverse line-shaped region in the case where the first type regions A**1** whose number was specified by the first type region proportion RA**1** were equally distributed within the target region A**10**.

The transverse-maximum-consecutive-number expected value NccE (hereinafter referred to also as a "transverse consecution expected value NccE") is the expected value of the transverse maximum consecutive number Ncc (that is, the maximum value of the number of the first type regions **A1** included in one transverse consecutive portion). This transverse consecution expected value NccE is calculated from the transverse maximum consecutive number Ncc that can be achieved based on the first-type-region-number expected value NcE and the combination number CNcc of the arrangements of the first type regions **A1** for realizing this transverse maximum consecutive number Ncc. Specifically, the sum of "Ncc*CNcc" regarding all achievable Ncc is divide by the sum of "CNcc" regarding all achievable Ncc. The obtained value is the transverse consecution expected value NccE. That is, the transverse consecution expected value NccE is the average value of the transverse maximum consecutive numbers Ncc in a plurality of arrangement patterns that can be achieved by the first type region **A1** and the second type region **A2**. Here, the total number of the first type region **A1** included in one transverse line-shaped region is fixed to the first-type-region-number expected value NcE regardless of the transverse maximum consecutive number Ncc. The transverse maximum consecutive number Ncc that can be achieved based on the first-type-region-number expected value NcE is determined corresponding to the first-type-region-number expected value NcE from a range that is larger than zero and equal to or less than the first-type-region-number expected value NcE.

Firstly, a description will be given of the case where the first-type-region-number expected value NcE is "4." In this case, the achievable transverse maximum consecutive numbers Ncc are "4," "3," "2," and "1." The following describes the respective combination numbers CNcc of these transverse maximum consecutive numbers Ncc.

In the case where Ncc=4, one transverse line-shaped region (that is, nine square regions **A20**) is decomposed into one transverse consecutive portion (constituted of four first type regions **A1**) and five second type regions **A2**. The one transverse consecutive portion and the five second type regions **A2** are arranged in one row. Here, the position of the one transverse consecutive portion is selected from six candidate positions formed by the five second type regions **A2** arranged in one row. Here, one second type region **A2** is expressed by a character "O" and the candidate position of the transverse consecutive portion is expressed by a character "X." In this case, the arrangement of the second type region **A2** (O) and the candidate position (X) is "XOXOXOXOXOX." The combination number CNcc of the arrangement of the first type region **A1** for realizing "Ncc=4" is the same as the permutation (${}_6P_1$=6) in the case where the position of the one transverse consecutive portion is selected from the six candidate positions (X).

In the case where Ncc=3, one transverse line-shaped region is decomposed into one transverse consecutive portion (constituted of three first type regions **A1**), one first type region **A1**, and five second type regions **A2**. The arrangement of the transverse consecutive portion and the first type region **A1** in the positions adjacent to each other is not allowed. In this case, the combination number CNcc is the same as the permutation (${}_6P_2$=30) in the case where the position of one transverse consecutive portion and the position of one first type region **A1** are selected from the six candidate positions.

In the case where Ncc=2, one transverse line-shaped region can be decomposed into the following two patterns.

First Pattern: two transverse consecutive portions and five second type regions **A2**

Second Pattern: one transverse consecutive portion, two first type regions **A1**, and five second type regions **A2**

In both patterns, the one transverse consecutive portion is constituted of the two first type regions **A1**.

In the first pattern, the arrangement of the two transverse consecutive portions in the positions adjacent to each other is not allowed. Additionally, the two transverse consecutive portions cannot be discriminated from each other. Accordingly, the combination number CNcc is the same as the number obtained by dividing the permutation (${}_6P_2$) in the case where the positions of the two transverse consecutive portions are selected from the six candidate positions by the permutation (${}_2P_2$=2!) of the two transverse consecutive portions that cannot be discriminated from each other. Specifically, CNcc=${}_6P_2$/2!=30/2=15.

In the second pattern, the arrangement of the transverse consecutive portion and the first type region **A1** in the positions adjacent to each other is not allowed. Additionally, the arrangement of the two first type regions **A1** in the positions adjacent to each other is also not allowed. The two first type regions **A1** cannot be discriminated from each other. Accordingly, the combination number CNcc is the same as the number obtained by dividing the permutation (${}_6P_3$) in the case where the three positions of the one transverse consecutive portion and the two first type region **A1** are selected from the six candidate positions by the permutation (${}_2P_2$=2!) of the two first type regions **A1** that cannot be discriminated from each other. Specifically, CNcc=${}_6P_3$/2!=120/2=60.

With the above description, in the case where Ncc=2, the final combination number CNcc is 75 (=15+60).

In the case where Ncc=1, one transverse line-shaped region is decomposed into four first type regions **A1** and five second type regions **A2**. Here, the consecution of two or more first type regions **A1** is not allowed. Additionally, the four first type regions **A1** cannot be discriminated from each other. Accordingly, the combination number CNcc is the same as the number obtained by dividing the permutation (${}_6P_4$) in the case where the positions of the four first type regions **A1** are selected from the six candidate positions by the permutation (${}_4P_4$=4!) of the four first type regions **A1** that cannot be discriminated from each other. Specifically, CNcc=6P_4/**4**!=360/24=15.

With the above description, the total number (that is, the summed value of the combination number CNcc) of the arrangements of the four first type regions **A1** in the case where the first-type-region-number expected value NcE is 4 is 126 (=6+30+75+15). The transverse consecution expected value NccE is calculated as follows.

$$\Sigma(Ncc*CNcc)=(4*6)+(3*30)+(2*75)+(1*15)=24+90+150+15=279$$

$$NccE=\Sigma(Ncc*CNcc)/\Sigma(CNcc)=279/126=2.21$$

(the operation symbol "Σ" denotes the sum for all achievable Ncc (the same shall apply hereafter))

Accordingly, in the case where the first-type-region-number expected value NcE is "4," the transverse consecution expected value NccE is 2.21.

The following describes the case where the first-type-region-number expected value NcE is "8." In this case, the achievable transverse maximum consecutive numbers Ncc are "8," "7," "6," "5," and "4." Here, Ncc of three or less cannot be used. In the case where Ncc=3, eight first type regions **A1** are decomposed into at least three portions that are separated from one another (the respective total numbers of the first type regions **A1** in the three portions are 3, 3, and 2). To separate these three portions from one another, at least two second type regions **A2** are required. Thus, one transverse line-shaped region requires 10 square regions **A20**. However, as described above, since the total number of the square regions **A20** included in one transverse line-shaped region is 9, Ncc=3 is not achieved. The same applies to the case where the transverse maximum consecutive number Ncc is 2 or less.

In the case where Ncc=8, one transverse line-shaped region is decomposed into one transverse consecutive portion (constituted of eight first type regions **A1**) and one second type region **A2**. Here, the one second type region **A2** is expressed by a character "O." The candidate position of the one transverse consecutive portion is expressed by a character "X." In this case, the arrangement of the second type region **A2** (O) and the candidate position (X) is "XOX." The combination number CNcc of the arrangement of the first type region **A1** for realizing "Ncc=8" is the same as the permutation (${}_2P_1=2$) in the case where the position of the one transverse consecutive portion is selected from the two candidate positions (X).

In the case where Ncc=7, one transverse line-shaped region is decomposed into one transverse consecutive portion (constituted of seven first type regions **A1**), one first type region **A1**, and one second type region **A2**. The arrangement of the transverse consecutive portion and the first type region **A1** in the positions adjacent to each other is not allowed. Accordingly, the combination number CNcc is the same as the permutation (${}_2P_2=2$) in the case where the position of the one transverse consecutive portion and the position of the one first type region **A1** are selected from the two candidate positions.

In the case where Ncc=6, one transverse line-shaped region is decomposed into two transverse consecutive portions with mutually different sizes and one second type region **A2**. The respective total numbers of the first type regions **A1** of the two transverse consecutive portions are 6 and 2. In the case where Ncc=5, similarly, one transverse line-shaped region is decomposed into two transverse consecutive portions with mutually different sizes and one second type region **A2**. The respective total numbers of the first type region **A1** of the two transverse consecutive portions are 5 and 3. In these cases, the combination number CNcc is the same as the permutation (${}_2P_2=2$) in the case where the positions of the two transverse consecutive portions are selected from the two candidate positions.

In the case where Ncc=4, one transverse line-shaped region is decomposed into two transverse consecutive portions with the same size and one second type region **A2**. The total numbers of the first type regions **A1** of the two transverse consecutive portions are 4. The two transverse consecutive portions cannot be discriminated from each other. Accordingly, the combination number CNcc is the same as the number obtained by dividing the permutation (${}_2P_2$) in the case where the positions of the two transverse consecutive portions are selected from the two candidate positions by the permutation (${}_2P_2=2!$) of the two transverse consecutive portions that cannot be discriminated from each other (specifically, "1").

With the above description, the total number (that is, the summed value of the combination numbers CNcc) of the eight first type regions **A1** in the case where the first-type-region-number expected value NcE is 8 is 9 (=2+2+2+2+1). The transverse consecution expected value NccE is calculated as follows.

$$\Sigma(Ncc*CNcc)=(8*2)+(7*2)+(6*2)+(5*2)+(4*1)=16+14+12+10+4=56$$

$$NccE=\Sigma(Ncc*CNcc)/\Sigma(CNcc)=56/9=6.2$$

Accordingly, in the case where the first-type-region-number expected value NcE is "8," the transverse consecution expected value NccE is 6.2.

In the case where the first-type-region-number expected value NcE is different from both of "4" and "8," similarly, the transverse consecution expected value NccE is calculated. Generally, the transverse-maximum-consecutive-number expected value NccE is can be calculated as follows.

(1) The first-type-region-number expected value NcE is calculated from the total number of the first type regions **A1** in the target region **A10**. For example, the first type region proportion RA**1** is calculated from the total number of the first type regions **A1** in the target region **A10**, and the first-type-region-number expected value NcE is calculated from the first type region proportion RA**1**.

(2) The achievable transverse maximum consecutive number Ncc is specified based on the first-type-region-number expected value NcE.

(3) For each achievable transverse maximum consecutive number Ncc, the combination number CNcc of the arrangements of the first type regions **A1** for realizing the transverse maximum consecutive number Ncc is calculated. For example, one transverse line-shaped region is decomposed into a plurality of elements corresponding to the first-type-region-number expected value NcE and the transverse maximum consecutive number Ncc. Corresponding to the decomposition result, the combination number CNcc of the arrangements of NcE pieces of the first type regions **A1** for realizing the transverse maximum consecutive number Ncc is calculated.

(4) The transverse consecution expected value NccE is calculated in accordance with the operation expression "NccE=Σ(Ncc*CNcc)/Σ(CNcc)."

The following describes other parameters in Table 2. The transverse-maximum-consecutive-number average value NccA (hereinafter referred to also as a "transverse consecution average value NccA") is the average value of the transverse maximum consecutive numbers Ncc of 12 transverse line-shaped regions. The continuity judgment result denotes the comparison result between the transverse consecution average value NccA and the transverse consecution expected value NccE. The "A grade" denotes "NccA>NccE" and the "B grade" denotes "NccA≤NccE." The A grade of the continuity judgment result means that the actually measured average value NccA of the transverse maximum consecutive number Ncc is larger than the expected value NccE of the transverse maximum consecutive number Ncc. That is, the A grade denotes excellent continuity of the first type region **A1** within the transverse line-shaped region. In this case, it is estimated that the current is likely to flow along the transverse line-shaped region.

C-2. Configuration of Resistor Element **70** and Evaluation Result:

As shown in Table 2, the respective continuity judgment results of No. T**1** to No. T**5** were the A grade, the A grade, the A grade, the A grade, and the B grade. As shown by these samples, the load-life evaluation result was 5 points in the case where the continuity judgment result was the B grade while being 10 points in the case where the continuity judgment result was the A grade. As the reason for this result, it is estimated that this is because the continuity of the first type region **A1** within the transverse line-shaped region is excellent in the case where the continuity judgment result is the A grade as described above and thus the current is likely to be dispersed along the transverse line-shaped region.

As described above, in the second judgment test, "Energy Output from Power Source in 1 Cycle" is large compared with the first judgment test. Also under this severe condition, the load-life evaluation result of 10 points was able to be achieved in the case where the continuity judgment result is the A grade, that is, in the case where the transverse consecution average value NccA was larger than the transverse consecution expected value NccE. Thus, the transverse consecution average value NccA is preferred to be larger than the transverse consecution expected value NccE. However, since the second evaluation test was performed under the relatively severe condition, it is estimated that a practicable load life is achieved even when the transverse consecution average value NccA is equal to or less than the transverse consecution expected value NccE.

Here, the respective transverse consecution average values NccA of No. T**1** to No. T**5** were 7.33, 1.83, 1.75, 2.50, and 2.18. Any value selected from these five values can be adopted as the lower limit of a preferred range (the lower limit or more and the upper limit or less) of the transverse consecution average value NccA. In the five values, any value of the lower limit or more can be adopted as the upper limit. Additionally, in the five values, the transverse consecution average values NccA that can achieve the load-life evaluation result of 10 points were 1.75, 1.83, 2.50, and 7.33. The upper limit and the lower limit in the preferred range of the transverse consecution average value NccA may be selected from these four values. However, since the second evaluation test was performed under the relatively severe condition, it is estimated that a practicable load life can be achieved even when the transverse consecution average value NccA is out of the preferred range.

The respective transverse consecution expected values NccE of No. T**1** to No. T**5** were 6.2, 1.67, 1.67, 2.21, and 2.21. Any value selected from these five values can be adopted as the lower limit of a preferred range (the lower limit or more and the upper limit or less) of the transverse consecution expected value NccE. In the five values, any value of the lower limit or more can be adopted as the upper limit. Additionally, in the five values, the transverse consecution expected values NccE that can achieve the load-life evaluation result of 10 points were 1.67, 2.21, and 6.2. The upper limit and the lower limit in the preferred range of the transverse consecution expected value NccE may be selected from these three values. However, since the second evaluation test was performed under the relatively severe condition, it is estimated that a practicable load life is achieved even when the transverse consecution expected value NccE is out of the preferred range.

Here, the respective parameters NL**1**, R, NL**2**, **300**L, and **70**D of No. T**1** to No. T**5** were as described in Table 2. As described above, since the second evaluation test was performed under the relatively severe condition, it is estimated that a practicable load life is achieved in the case where these parameters NL**1**, R, NL**2**, **300**L, and **70**D are different from the values of the above-described samples. In each case, it is estimated that setting at least the first type line number NL**1** within the above-described preferred range allows achieving the favorable radio-wave-noise evaluation result (for example, 2 points or more under the condition of the first evaluation test) and the favorable load-life evaluation result (for example, 2 points or more under the condition of the first evaluation test). Here, in addition to the first type line number NL**1**, the second type line number NL**2** is preferred to be set within the above-described preferred range. Additionally, the component ratio R is preferred to be set within the above-described preferred range. Additionally, the resistor element diameter **70**D is preferred to be set within the above-described allowable range. Additionally, the connecting portion length **300**L is preferred to be set within the above-described allowable range.

D. Modifications:

(1) The material of the resistor element **70** is not limited to the above-described material, and various materials can be adopted. As the glass, for example, glass containing one or more types of B_2O_3—SiO_2-based, BaO—B_2O_3-based, SiO_2—B_2O_3—CaO—BaO-based, SiO_2—ZnO—B_2O_3-based, SiO_2—B_2O_3—Li_2O-based, and SiO_2—B_2O_3—Li_2O—BaO-based glasses can be adopted. Additionally, the material that forms the aggregate is not limited to glass, and various ceramic materials such as alumina may be adopted. Alternatively, the mixture (for example, alumina) of glass and ceramic material may be adopted. In each case, the shape of the material particle that forms the aggregate is preferred to be flat. Thus, by applying the force in the direction parallel to the central axis CL to compress the material of the resistor element **70** during manufacture of the resistor element **70**, in the flat material particle, the direction of the short axis can be brought close to the direction parallel to the central axis CL and the direction of the long axis can be brought close to the direction perpendicular to the central axis CL. As a result, the zirconia portion P**1** (in FIG. **2**) that extends in the direction intersecting with the central axis CL can be simply formed. That is, the first type line number NL**1** and the second type line number NL**2** can be simply increased. Here, the long axis of the flat particle is the axis forming the maximum outer diameter of the particle. The short axis of the flat particle is the axis forming the minimum outer diameter of the particle. To realize the first type line number NL**1** within the above-described preferred range, the aspect ratio (the length (maximum outer diameter) of the long axis: the length (minimum outer diameter) of the short axis) of the material particle of the aggregate is preferred within the range of "1:0.4" to "1:0.7."

Here, the line numbers NL**1** and NL**2** can simply be adjusted by adjusting the aspect ratio of the material particle of the aggregate and the collapsibility of the material particle (in particular, the glass particle) of the aggregate. For example, increasing the length of the long axis with respect to the length of the short axis allows increasing the line numbers NL**1** and NL**2**. Additionally, increasing the collapsibility of the glass particle allows increasing the line numbers NL**1** and NL**2**.

The transverse consecution average value NccA can simply be adjusted by adjusting the aspect ratio of the material particle of the aggregate, the collapsibility of the material particle (in particular, the glass particle) of the aggregate, and the proportion (for example, weight percent) of the material of the filler and the proportion of the conductive material in the material of the resistor element **70**. For example, while the length of the long axis with respect to the length of the short axis in the material particle of the aggregate is increased, the proportion of the material of the filler and the proportion of the conductive material are increased. This allows increasing the transverse consecution average value NccA. Additionally, while the collapsibility of the glass particle is increased, the proportion of the material of the filler and the proportion of the conductive material are increased. This allows increasing the transverse consecution average value NccA. Thus, increasing the transverse consecution average value NccA allows achieving the transverse consecution average value NccA larger than the transverse consecution expected value NccE.

(2) The shape of the resistor element **70** is not limited to the approximately cylindrical shape, and any shape can be adopted. For example, the through hole **12** of the insulator **10** may include a portion whose inner diameter changes toward the front end direction D**1**. The resistor element **70** may be formed in the portion whose inner diameter changes. In this case, the resistor element **70** includes a portion whose outer diameter changes toward the front end direction D**1**. The radio-wave-noise evaluation result and the load-life evaluation result are estimated to be affected by a portion with a small outer diameter in the resistor element **70**. Accordingly, generally, in the cross section perpendicular to the axial line CL in the resistor element **70**, the minimum value of the outer diameter of the portion in contact with the inner peripheral surface of the through hole **12** of the insulator **10** over the whole circumference is preferred to be within the above-described preferred range of the resistor element diameter **70**D.

In each case, it can be said that when the first type line number NL**1** calculated using the target region A**10** arranged in at least one position on the cross section including the central axis CL of the resistor element **70** is within the above-described preferred range, the first type line number NL**1** of the resistor element **70** is within the preferred range. It is estimated that when the first type line number NL**1** of the resistor element **70** is within the preferred range, the suppression performance of the radio wave noise and the service life of the resistor element can be improved. The same applies to the second type line number NL**2**.

(3) The configuration of the spark plug is not limited to the configuration described in FIG. **1**, and various configurations can be adopted. For example, a noble metal tip may be disposed in the portion that forms the gap g in the ground electrode **30**. As the material of the noble metal tip, a material containing various noble metals such as iridium and platinum can be adopted. Similarly, a noble metal tip may be disposed in the portion that forms the gap g in the center electrode **20**.

The present invention has been described above based on the embodiment and the modifications. The above-described embodiments of the invention are for ease of understanding of the present invention and do not limit the present invention. The present invention may be modified or improved without departing from the gist and the claims of the present invention, and includes the equivalents.

DESCRIPTION OF REFERENCE SIGNS

5 Gasket
6 First rear-end-side packing
7 Second rear-end-side packing
8 Front-end-side packing
9 Talc
10 Insulator (ceramic insulator)
11 Second outer-diameter contracted portion
12 Through hole (shaft hole)
13 Nose portion
14 Rear opening
15 First outer-diameter contracted portion
16 Inner-diameter contracted portion
17 Front-end-side trunk portion
18 Rear-end-side trunk portion
19 Flange portion
20 Center electrode
21 Outer layer
22 Core portion
23 Head
24 Flange portion
25 Nose portion
29 Front end surface
30 Ground electrode
31 Front end portion
35 Base material
36 Core portion
40 Terminal metal fitting
50 Metal shell
51 Tool engagement portion
52 Screw portion
53 Crimp portion
54 Seat portion
55 Trunk portion
56 Inner-diameter contracted portion
58 Deformed portion
59 Through hole
60 First seal portion
70 Resistor element
70D Outer diameter (resistor element diameter)
70L Resistor element length
80 Second seal portion
100 Spark plug
300 Connecting portion
300L Connecting portion length
400 Partial cross section
g Gap
R Component ratio
D**1** Front end direction
D**1***r* Rear end direction
A**1** First type region
A**2** Second type region
CL Central axis (axial line)
Ac Conductive region
Nc First type region number
Aa Aggregate region
Pg Portion
P**3** Other component portion
P**2** Titania portion
P**1** Zirconia portion
A**10** Target region
L**01** to L**12** Transverse line-shaped region
La First length
A**20** Square region
Lb Second length
NL**1** First type line number
NL**2** Second type line number
Ncc Transverse maximum consecutive number

Having described the invention, the following is claimed:

1. A spark plug, comprising:

an insulator that has a through hole extending in a direction of an axial line;

a center electrode at least partially inserted into a front end side of the through hole;

a terminal metal fitting at least partially inserted into a rear end side of the through hole; and

a connecting portion electrically connecting the center electrode and the terminal metal fitting together within the through hole, wherein

the connecting portion includes a resistor element,

the resistor element includes an aggregate, a filler containing ZrO_2, and carbons, and

in a cross section including the axial line of the resistor element, when:

a center line is defined by the axial line, a target region is defined by a rectangular region where a size in a direction perpendicular to the axial line is 1800 μm and a size in a direction of the axial line is 2400 μm;

a transverse line-shaped region is defined by a line-shaped region, the line-shaped region being constituted of nine square regions arranged in the direction perpendicular to the axial line in the case where the target region is divided into a plurality of square regions, the square region having a length of 200 μm on a side;

a first type region is defined by the square region where a proportion of an area of ZrO_2 is 25% or more; and

a second type region is defined by the square region where a proportion of an area of ZrO_2 is less than 25%,

a total number of the transverse line-shaped regions including two or more of the first type regions is equal to or more than 5.

2. The spark plug according to claim **1**, wherein

a total number of the transverse line-shaped regions including two or more of the consecutive first type regions is equal to or more than 5.

3. The spark plug according to claim **1**, wherein

the filler contains TiO_2, and

a weight proportion of Ti to Zr in the resistor element is equal to or more than 0.05 and equal to or less than 6.

4. The spark plug according to claim **1**, wherein

in a cross section pernendicular to the axial line in the resistor element, a minimum value of an outer diameter of a portion in contact with an inner peripheral surface of the insulator over a whole circumference is equal to or less than 3.5 mm.

5. The spark plug according to claim **4**, wherein

the minimum value of the outer diameter is equal to or less than 2.9 mm.

6. The spark plug according to claim **1**, wherein

a distance in the axial line between a rear end of the center electrode and a front end of the terminal metal fitting is equal to or more than 15 mm.

7. The spark plug according to claim **1**, wherein

when: a longitudinal line-shaped region is defined by a line-shaped region that is constituted of 12 of the square regions arranged in a direction parallel to the axial line; and a longitudinal maximum consecutive number is defined by a maximum value of a consecutive number of the first type regions in one longitudinal line-shaped region, an average value of the longitudinal maximum consecutive number in nine longitudinal line-shaped regions included in the target region is equal to or less than 5.0.

8. The spark plug according to claim **1**, wherein

a total number of the transverse line-shaped regions including two or more of the consecutive first type regions is equal to or more than 7.

9. The spark plug according to claim **1**, wherein

when a transverse maximum consecutive number is defined by a maximum value of a consecutive number of the first type regions in one transverse line-shaped region, an average value of the transverse maximum consecutive number in 12 transverse line-shaped regions included in the target region is larger than an expected value of the transverse maximum consecutive number calculated from a total number of the first type regions in the target region.

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